Possibilities & Limitations of Extending the Wholesale / Bulk Power Transactive Techniques to Retail Markets & Distribution Operations

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What is Markets 3.0?

U.S. wholesale electricity markets are characterized by the following trends:

- *Need to manage new products*
  e.g., Demand Response, Variable Energy Resources, Microgrids, Self-Optimizing Customers & Energy Storage
- *Penetration of & coupling with retail resources*
  use of distributed generation and smart load resources from the industrial, commercial and residential sectors

Recent History
FERC NOI & NOPR on VER Integration & Cost Allocation
FERC Report on Demand Response & NOPR 745 on compensation
FERC NOPR on Fast Regulation from Storage

Real-time wholesale markets meet retail resources

Markets 3.0 *2011-2020*
- Dynamic retail pricing
- DR for ancillary services
- Capacity markets for firming & DR
- Intra-hr scheduling of renewables
- Storage as a resource

Markets 2.0 *2001-2010*
- Co-optimized energy & ancillary services
- Congestion pricing
- Nodal real time dispatch
- Capacity markets for DR

Markets 1.0 *1995 - 2003*
- Wholesale day ahead energy on hourly schedules
- Ancillary services
- Balancing and regulation
- Transmission rights

Integrating Distributed Energy Resources

- Early euphoria being subdued by challenge realization!
  - Visibility – no telemetry (AMI is *NOT* the solution !)
  - Control (Definitely NOT AMI; multiple technologies for each end use / resource
  - Grid Security - Backfeed, fault ride through, frequency response
  - Market Integration "estimated response" for settlements; estimating elasticity in market clearing
- DER Categories
  - Distributed Generation – PV, CHP, micro-wind
  - Distributed Storage
  - Dynamic Pricing – autonomous demand price elasticity
  - Dispatchable Demand Response

Integrating Demand Response: Key Research Questions

- What are the potential impacts of greater DR integration into the wholesale market?
  - What are the effects on real time markets prices & supply dispatch over time?
  - What are the conditions for preserving market convergence?
- Dispatchable Demand Response (DDR):
  - planned changes in consumption in response to direction from someone other than the customer
  - modeled as a supply resource dispatched similarly to generation
- Dynamic Pricing (DP) response:
  - customer decides whether and when to reduce consumption
  - modeled as a voluntary customer response to market prices

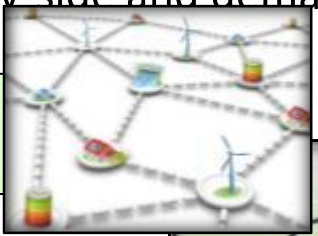
DNV KEMA study with NYISO, *Market Dynamics of Integrating Demand Response into Wholesale Energy Markets*, The Electricity Journal, April 1, 2013.

Categories of Distributed Energy Resources

- Distributed Energy Resources (DERs) include a variety of supply-side and demand-side resources. Those examined in this study include:

Relative Forecasting Complexity

SOC – Self Optimizing Customers



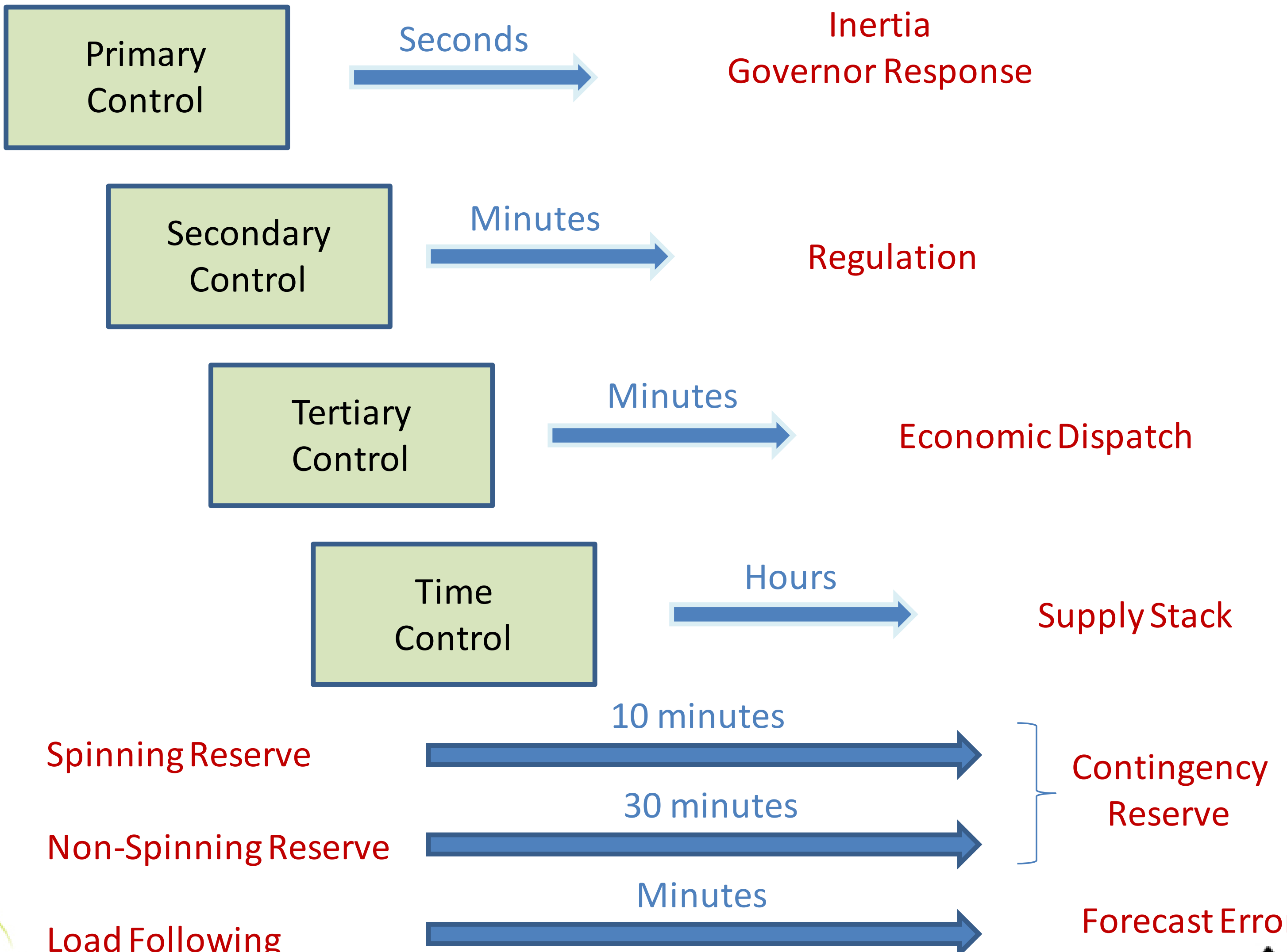
DR – Demand Response (Including Autonomous Price Responsive Load (Dynamic Pricing)

DES – Distributed Energy Storage

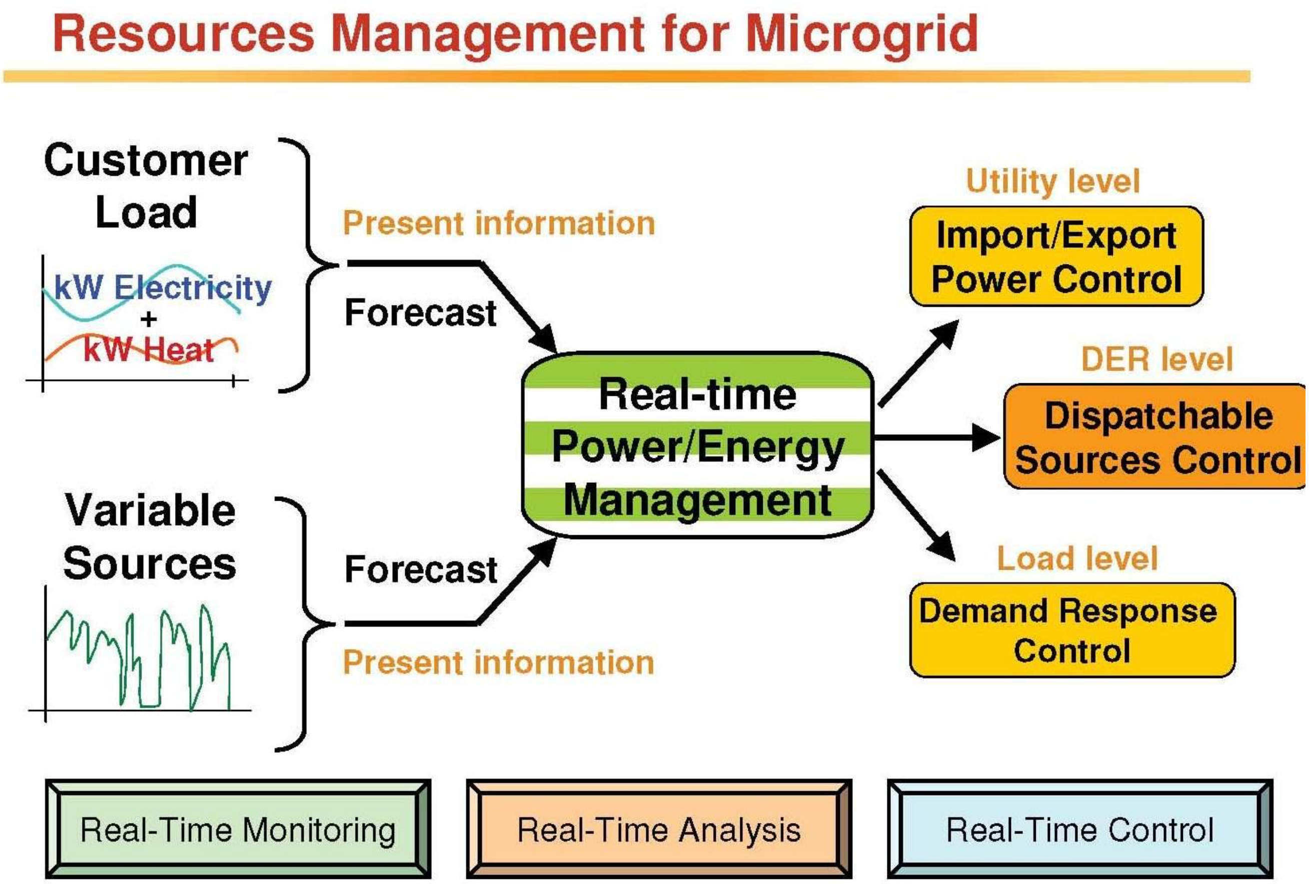
DG – (PV – Distributed and "Behind-the-meter" PhotoVoltaics; CHP – Combined Heat and Power)

PEV – Plug in Electric Vehicles

Time Domains for Flexibility



Microgrid Resource Configuration



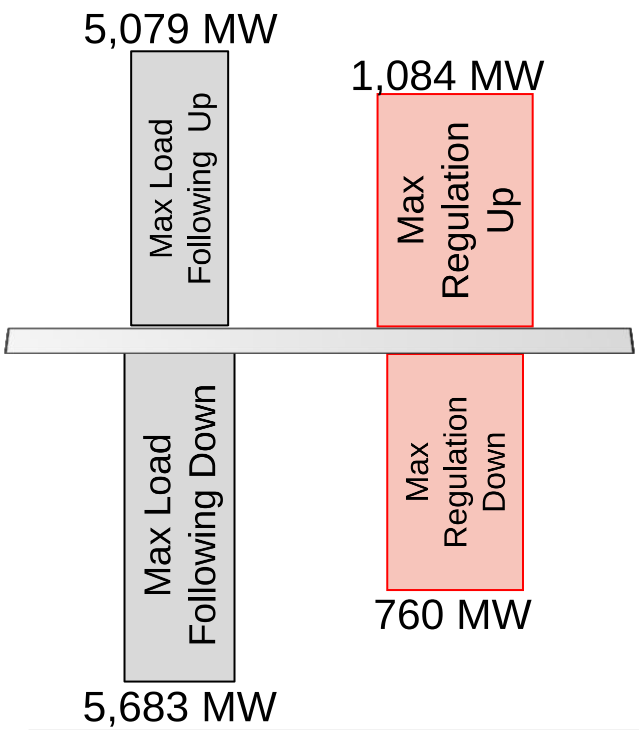
Source: Quanta

Impacts by DER Type & Penetration

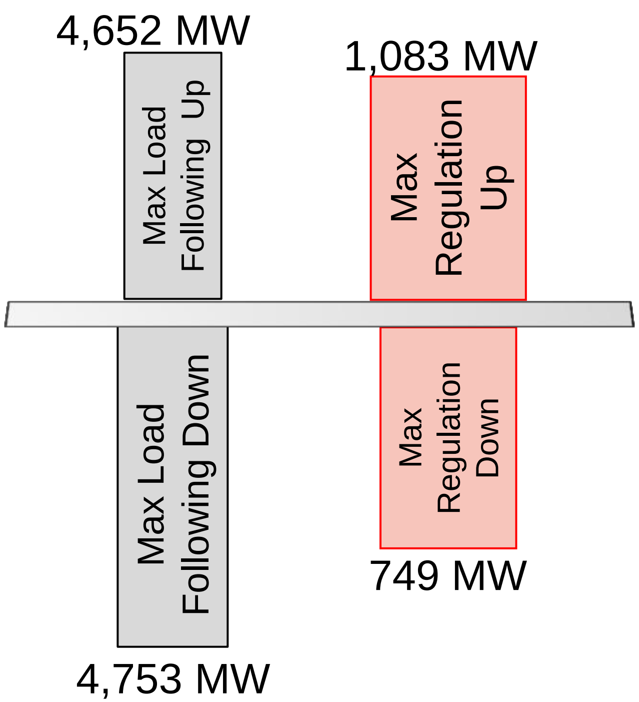
DER Profile*	High DER (Max MW)	Mid DER (Max MW)	Low DER (Max MW)	Penetration Assumptions	Variability Drivers
PV	7812	4757	1747	Scaled according to ISO scenarios for distributed PV	Clearness index and PV Technology. Based upon forecast errors calculated in LTPP High Load case.
CHP	4468	3092	1732	Based upon CEUS	Prices, temperature, conforming load
SOC	1277	806	337	Based upon CEUS	Prices, temperature, conforming load
PEV	-882	-662	-625	Based upon research by NREL	Commute time and traffic congestion
DES	-2808	-1920	-1033	Based upon CEUS	PV smoothing requirements and prices
DR	-2466	-1926	-1390	Based upon existing utility programs	Prices, load and temperature

High DER Penetration leads to forecast uncertainty and increased production costs.

Estimated Load Following & Regulation Requirements by Visibility Scenario



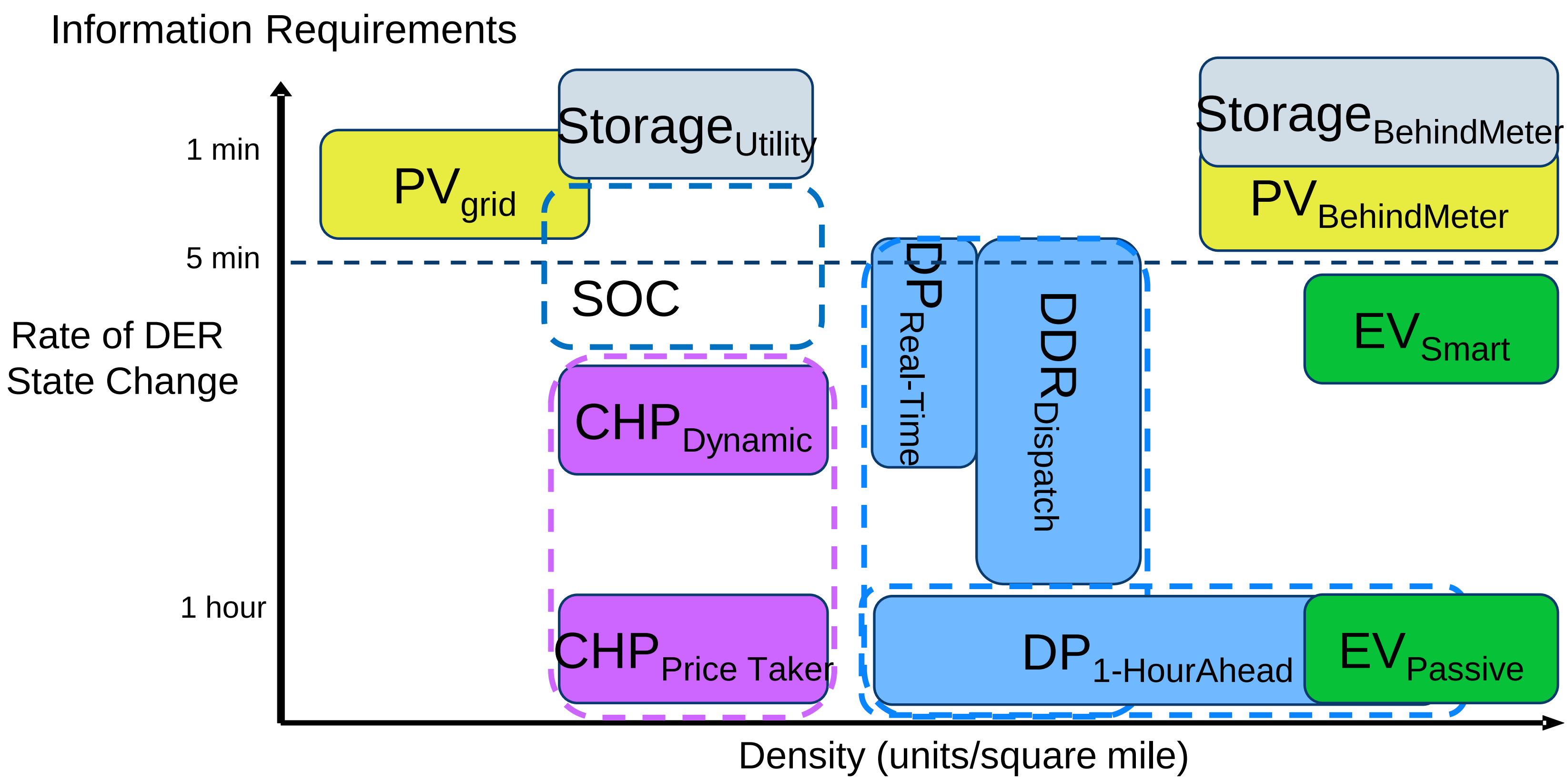
No Visibility Case



Visibility Case

Visibility provides a large reduction in the 95th percentile of Load Following requirements. Minimal Impact on Regulation.

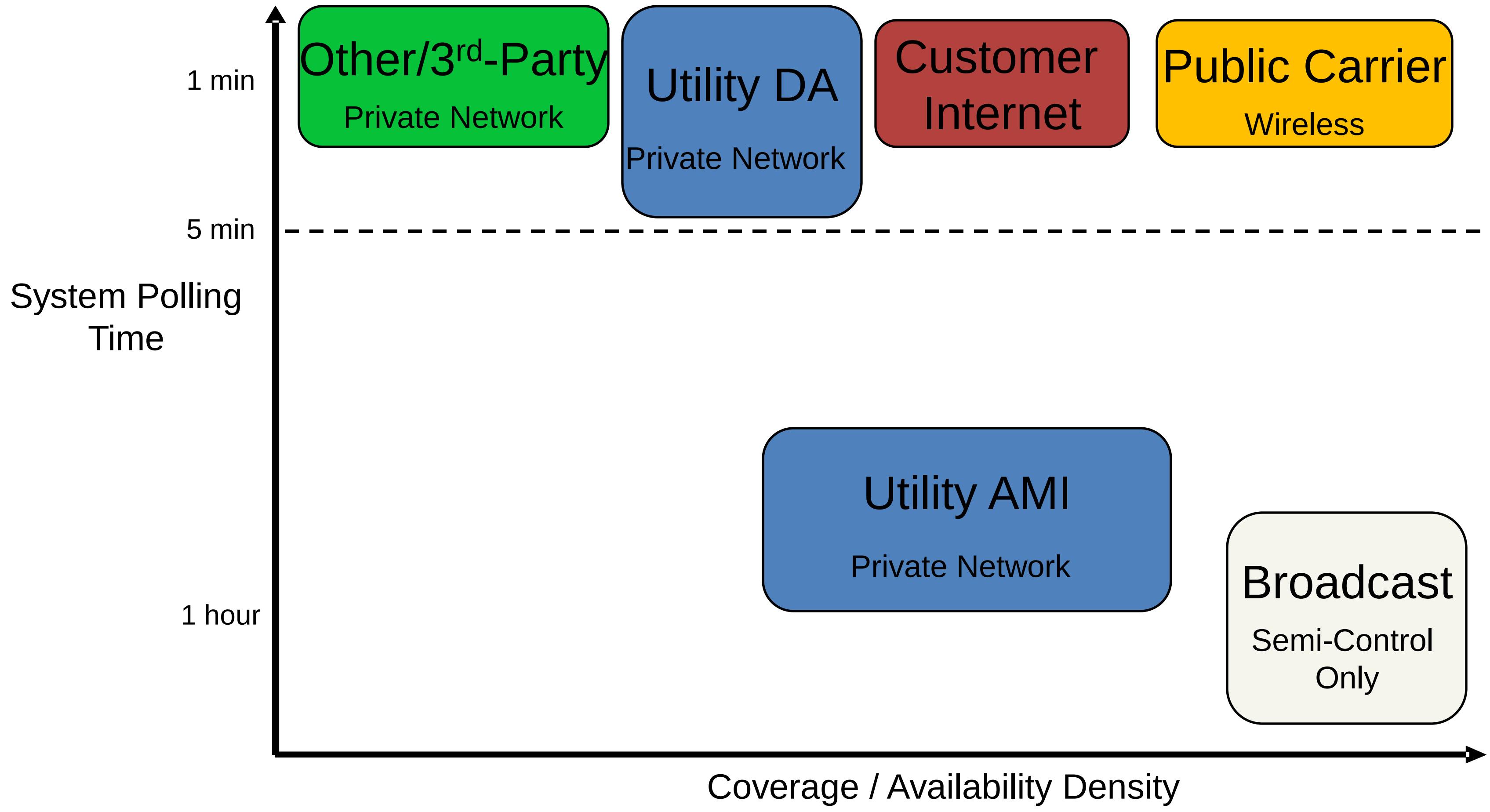
B. Technical requirements for monitoring and control to achieve market and operational benefits



Device density and rate of change are the drivers for communications technology and costs

Communication Architectures

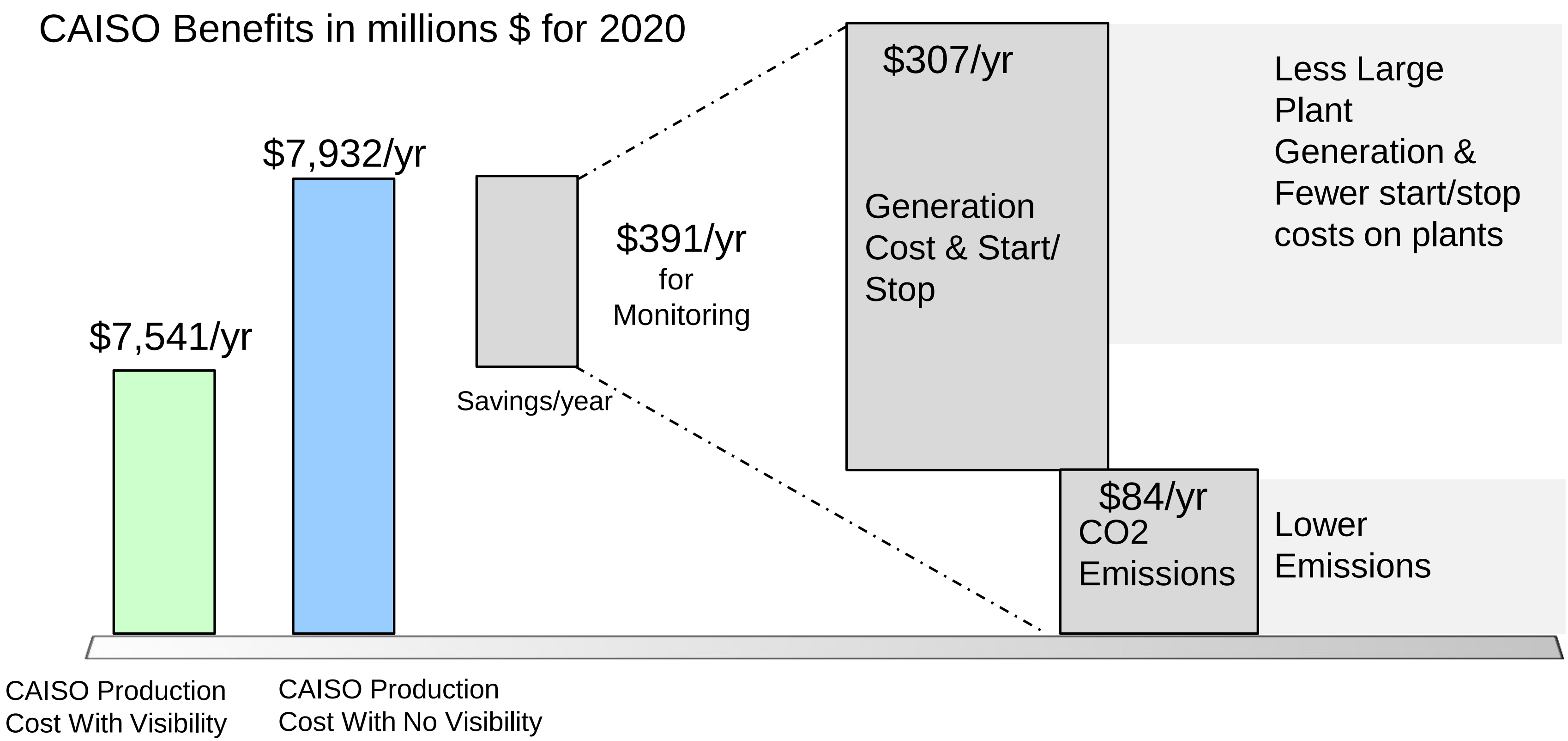
Various Stakeholders play in own time and density domain



Communications Architectures

Ownership / Timeline	UTILITY				COMMON CARRIER				3rd Party		
Present	SCADA	AMI Mesh Networks	Broadcast Radio		Cellular GPRS SMS		Wi-Fi	Internet POP / Ethernet/WiFi		BAS Networks - larger commercial	
Emerging	Distribution Automation	AMI Mesh Networks		700 MHz		Cellular LTE	Wi -Fi public hot spots	pervasive in C&I and most residences	EV GPRS/ Wireless	BAS penetration and Open ADR	DER maintenance via cellular / internet
2020	SCADA / DA on fiber / 700 MHz	not EOL for current AMI systems yet	migrated to other spectrum?	Adopted for DA and mobile apps/ AMI?	Not Available	next generation?	next evolution?	pervasive	EV on next generation	BAS ubiquitous in C&I	DER maintenance / ops via next generation
Pros	Low Latency NERC CIPS inherent for utility DER assets	Ubiquitous and Low Cost Modems Available	Very Low Cost	potential spectrum re-allocation to utility use.	ubiquitous and low costs already used for PV	ubiquitous high performance new cellular standard	low modem costs and nil data cost	ubiquitous and low modem / nil data cost	rely on auto industry directions and capabilities	support of Open ADR likely no incremental cost for DER	low incremental cost for DER monitoring
Cons	expensive / proprietary /not on LV	Utility owned and controlled provisions for 3rd party access	Ubiquitous but with spots of non-access only one way	Utility owned and controlled provisions for 3rd party access	obsolete and carriers will abandon 3-5 years	higher modem costs and higher service impacts/costs for DER data	not ubiquitous; security	authentication and validation required possibily encryption	proprietary and closed	proprietary and closed	proprietary and closed
DER Applications	Utilty scale PV and utility storage	Rooftop PV; Residential HVAC; Distributed Storage	small DR assets residential hot water and AC	Unknown adoption in CA	Distributed PV Residential AC distributed storage	GPRS targets	And DER near an Internet POP with WiFi access indoor esp	Any C&I facility DER and most residential	EV smart charging	commercial DER, all SOC, most CHP	distributed PV and distributed storage

C. What are the CAISO costs and expected benefits to increased DER visibility and control?



Benefits of monitoring and control are significant compared to the communication, monitoring, and forecasting infrastructure costs

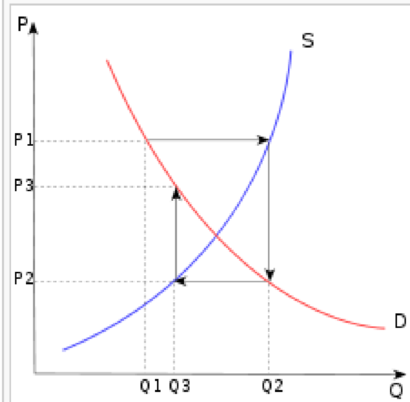
Price Elastic Load = Sequential

- Economists are familiar with the iterative interaction between elastic supply & elastic demand:

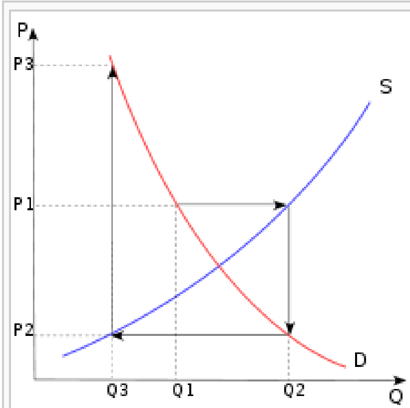
The "Cobweb Theorem"
- Relative elasticities dictate convergence or divergence

However, the Cobweb Theorem does not consider time dynamics

Key to Understanding Behavior:
- Price is a control signal
- Market clearing and the establishment of supply and demand curves are dynamic processes



The *convergent* case: each new outcome is successively closer to the intersection of supply and demand.



The *divergent* case: each new outcome is successively further from the intersection of supply and demand.

1. Market Measures / Forecasts Load
2. Market Clears the Supply Side Bids and Sets Prices
3. Load Reacts to Price
4. Repeat

- *Anecdote – UK in the 80's (courtesy of Richard Tabors)*
  - *First UK Markets had industrial customers exposed to market prices*
  - *Customers would react to prices once set*
  - *Some price oscillations observed*
    - *Market did not take elasticity / behavior into account*
- *Anecdote – A 2013 Swedish study had similar findings (Sweco Energy Markets)*

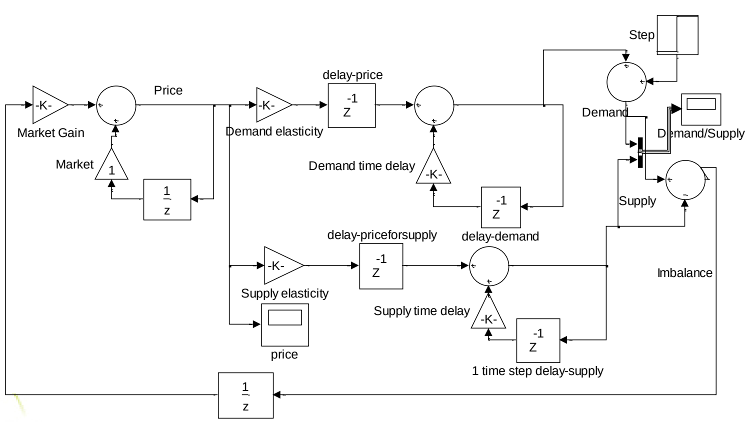
Market Models

Theory

Process Control Model

Simple market model based on control theory - captures generation & demand time dynamics

- Supply-demand imbalance is input to clearing function which adjusts price according to supply & demand elasticities.
- Feedback gain is inverse of sum of supply & demand elasticities. Delay equals periodicity of market clearing function.
- Critical parameters: price elasticity ratios, time delay ratios ; demand elasticity error

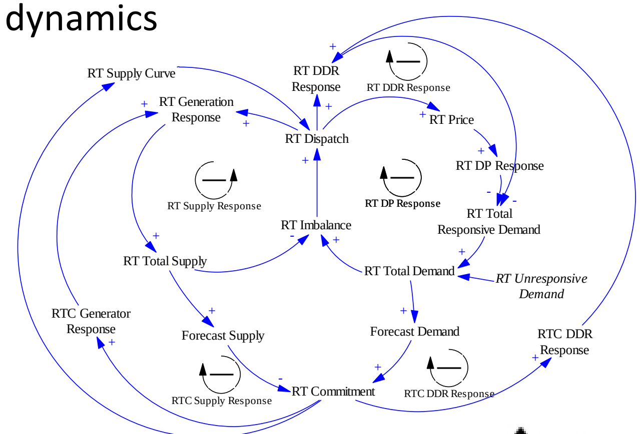


Simulation

System Dynamics Model

Detailed dynamic model of a market operation using system dynamics

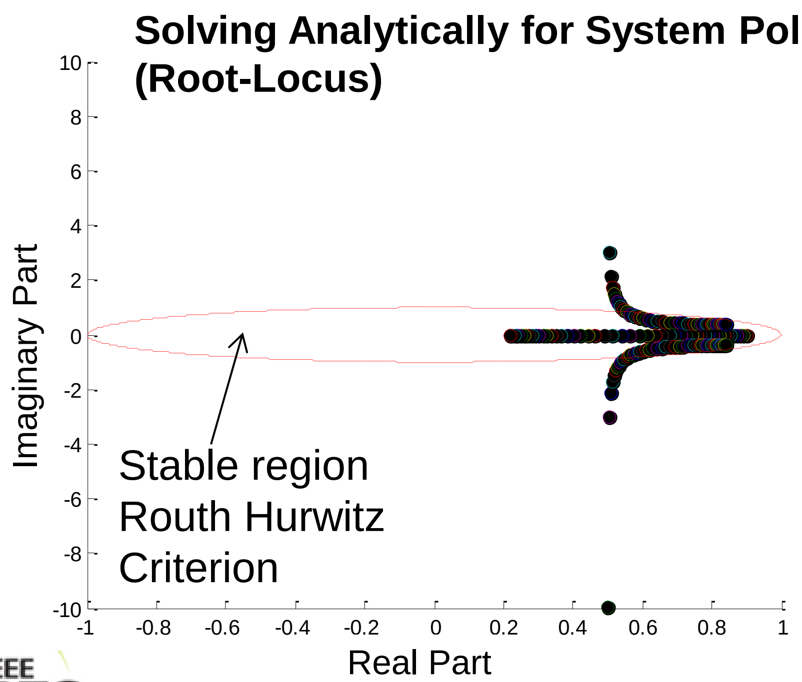
- Non-linear supply curves representative of a real market and non-linear demand curves based on published demand elasticity research.
- Integrates day ahead, hour ahead, and real time energy market processes.
- Includes residential and commercial end-uses (HVAC, lighting, water heating, refrigeration).
- Does not predict price but captures market dynamics



Control Theory Modeling Results

Under some scenarios of DR integration, the markets can become unstable.

- A simple example considers how the dynamic response of generation, demand, and market operations affect market stability over ranges of relative supply and demand elasticity.
- In this case, the market misestimates demand elasticity (i.e., 100% error)
- Where generation is less elastic than demand, the system goes unstable.



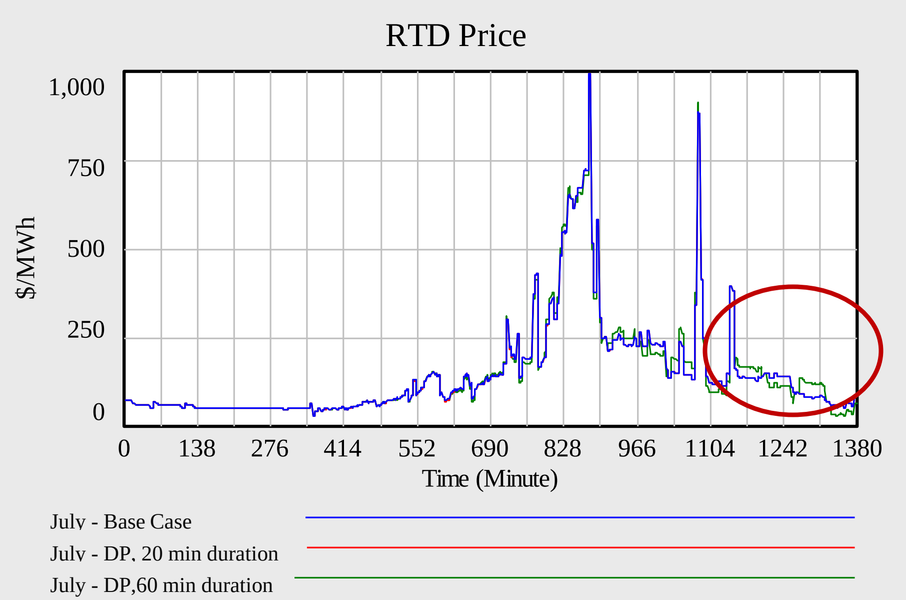
There are scenarios for which the overall system will not be stable when the market misestimating demand elasticity (i.e., 100% error). Misestimating elasticity is akin to operating the market as it is operated today.

The Real World is MUCH MORE Complex

- Multiple Markets – Day Ahead, Hour Ahead, Real Time
- Multiple Supply Resources with Different Time Dynamics
- Multiple Load Side Elements
- More Complex Load Side Behaviors
- Non-linear / Time Varying Elasticities

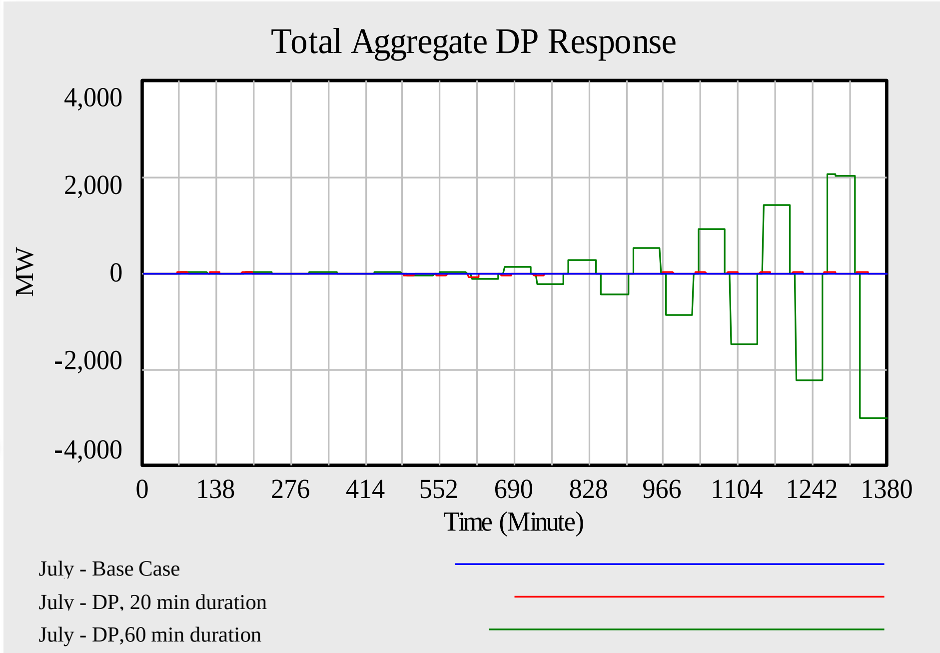
First Key Observation

Market impacts depend on: penetration, timing of price signals, and relative duration of DP compared to the frequency of the market dispatch & price publication.



DP responding to an hourly price signal with a 60 min duration affects RTD prices but 20 min durations do not.

At scaled up penetration, DP response becomes unstable as shown when the duration is 60 min. Added to information latencies, this means the market is clearing for load that responded to the prior period price but is not aware of that effect.



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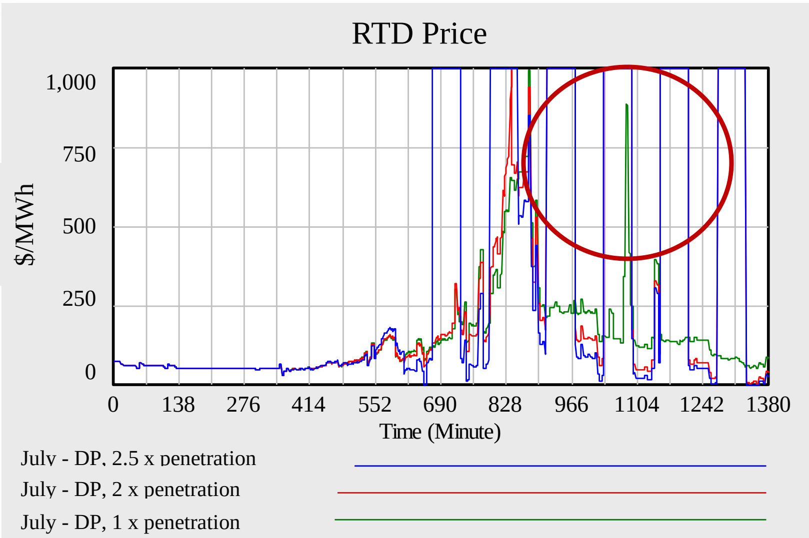
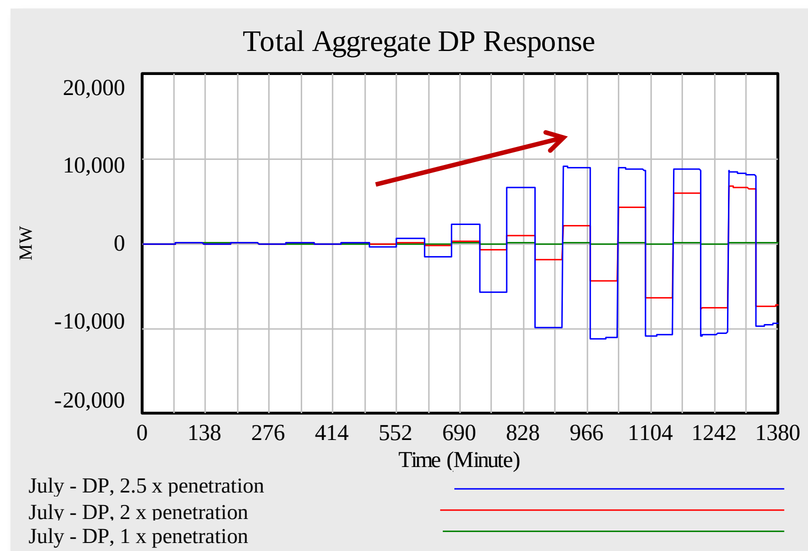
Second Key Observation

DP impacts are very sensitive to DP penetration, demand elasticity, and the accuracy of estimated demand elasticity in the market clearing algorithms.

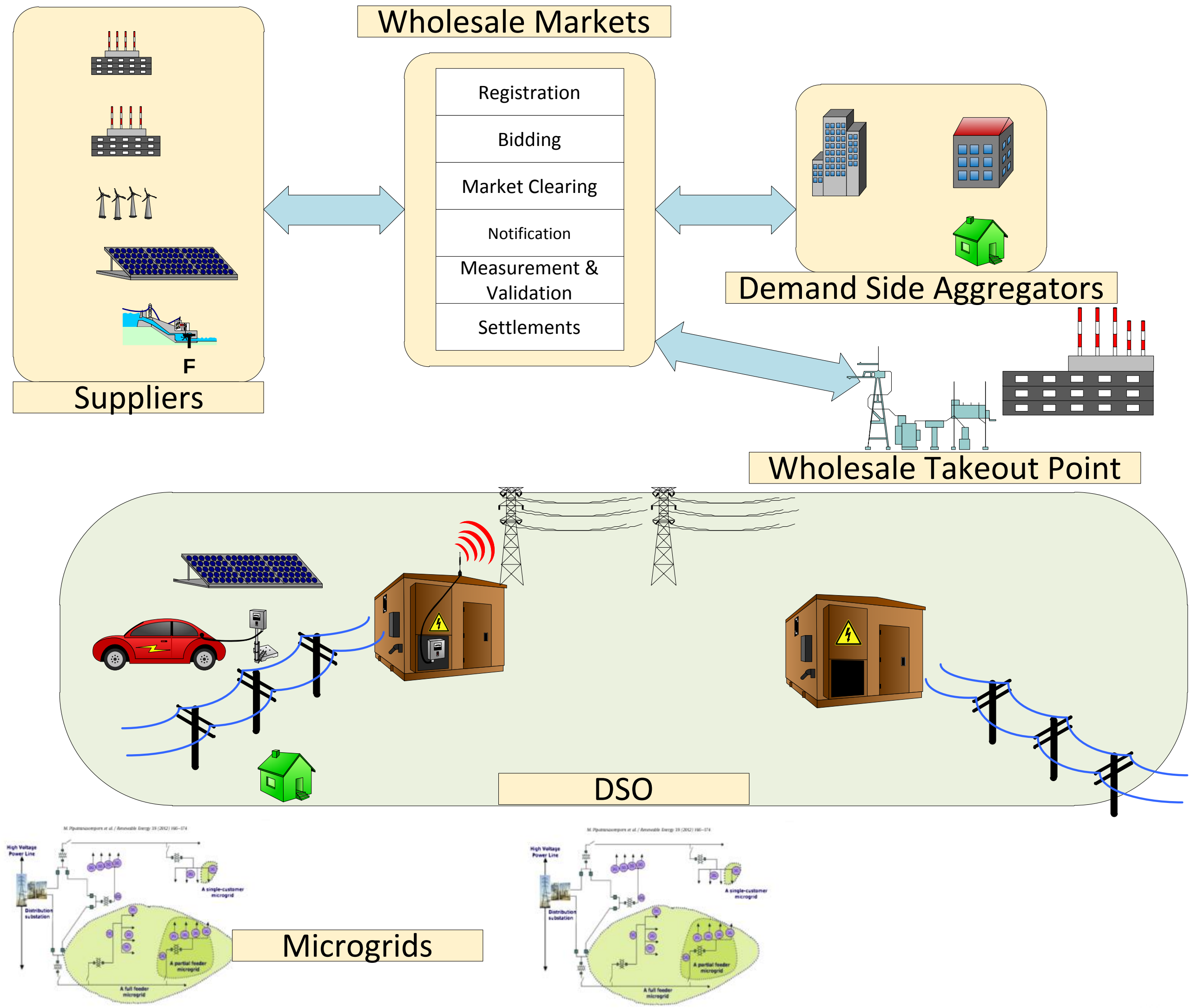


As the amount of responsive DP in the market increases, price potentially increases and can grow to be volatile



As the amounts of viable DP in the market grow, load oscillations grow. Increased "penetration" of DP in effect increases the ratio of demand elasticity to supply elasticity and increases instability.

Thinking about ISOs, DSOs & MGOs



The Devil is in the Details

Rules of the Game	• Can one entity have multiple roles? - Direct access; DSO resource; MGO
Bi-lateral Transactions & "Open Access Distribution" (OADIS)	• Some microgrid operators will have multiple sites on different takeout points (e.g., DOD)
Settlements	• What constitutes a revenue meter? - e.g., EV and chargers have meters and comms; why duplicate?
Validation	• The inevitable DR "what would it have been?" question
Market Co-ordination	• Timing of bidding closure, market clearing, notification across layers

Gaps in Understanding

- Information Arbitrage
  - Interaction of DSO and ISO markets in time and opportunity to influence pricing
  - Stability of Market Behavior with layered clearing processes
    - Interaction of gate closures, processing time, notification, participant decision making
- Business Models for New Resources in Markets

Business Models – Example - Storage

- Storage as a Generator
  - Must separately bid discharging and charging and take risks of not clearing / duplicate clearing
- Storage co-optimized by market operator
  - Basis of bidding? Paid clearing price like a generator?
  - New asset class offering storage services?
- Hybrid: Storage as a (regulated) asset class and 3rd parties "own" energy in storage

And – Reliability Issues

- Today DG MUST disconnect on grid low voltage for safety reasons
- At high penetrations this can cause grid level event “magnification”
  - Routine cleared line fault becomes loss of 000’s MW of PV
- So Fault Ride through, low voltage ride through standards needed
- And – rules on “pre-emptive disconnect”

Conclusions

- If We Want to Use Price as a Control Signal
  – Better do the Control Systems Design
  – Artificial Volatility is NOT a Good Thing
- The More Complex the Market Design – the More Opportunities for “Strategic Bidding” and Unexpected Outcomes